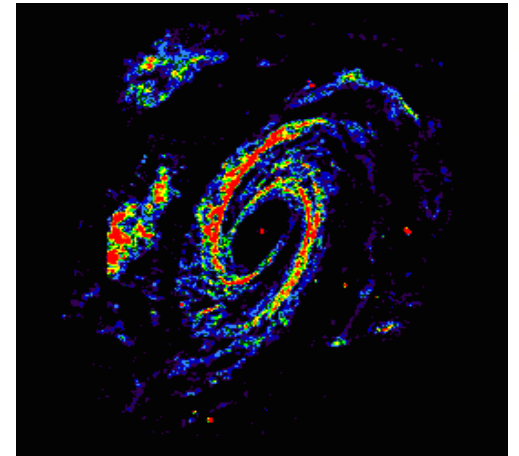
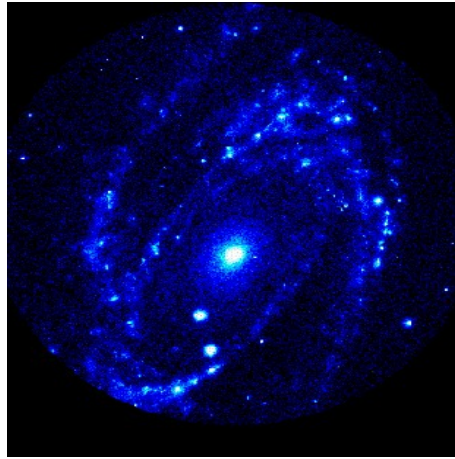
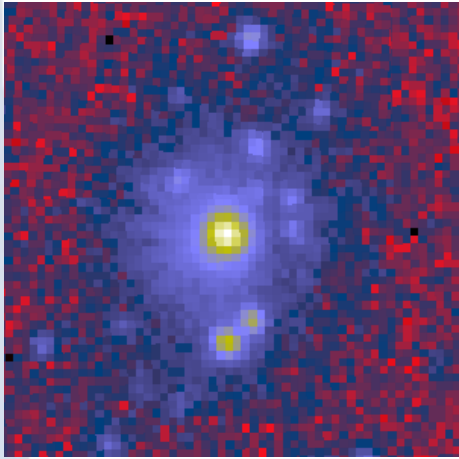


Multi-wavelength astronomy



Content

- What do we measure
- Multi-wavelength approach
- Data
 - Data Mining
 - Virtual Observatory
- Hands on session

Larmor's formula

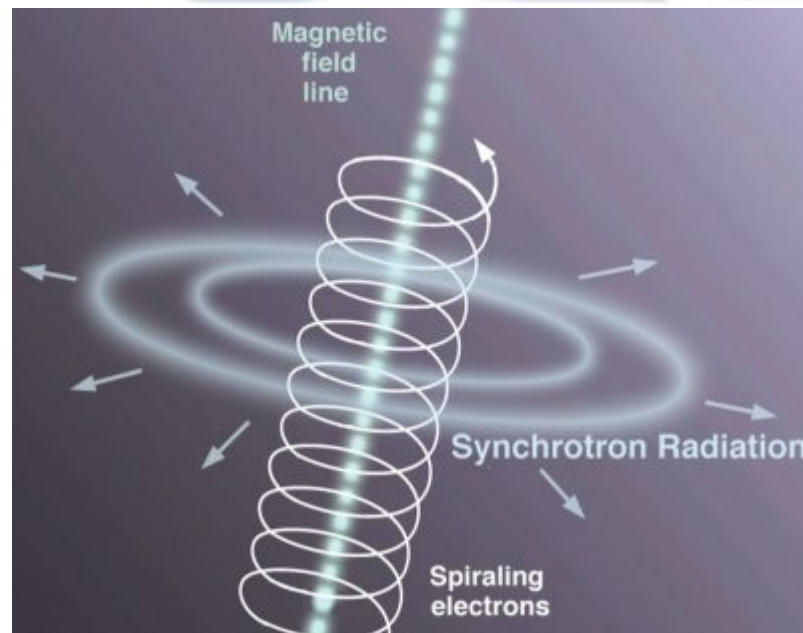
- Maxwell's equations imply that all classical electromagnetic radiation is ultimately generated by accelerating electrical charges.

$$P = \frac{2}{3} \frac{q^2 \dot{v}^2}{c^3} \quad (2D4)$$

- Larmor's equation - states that any charged particle radiates when accelerated and that the total radiated power is proportional to the square of the acceleration.
- Since the greatest astrophysical accelerations are usually electromagnetic, the acceleration is usually proportional to the charge/mass ratio of the particle.
- Thus radiation from electrons is typically $\approx 4 \times 10^6$ stronger than radiation from protons, which are $\approx 2 \times 10^3$ times more massive.

Magnetobremsstrahlung

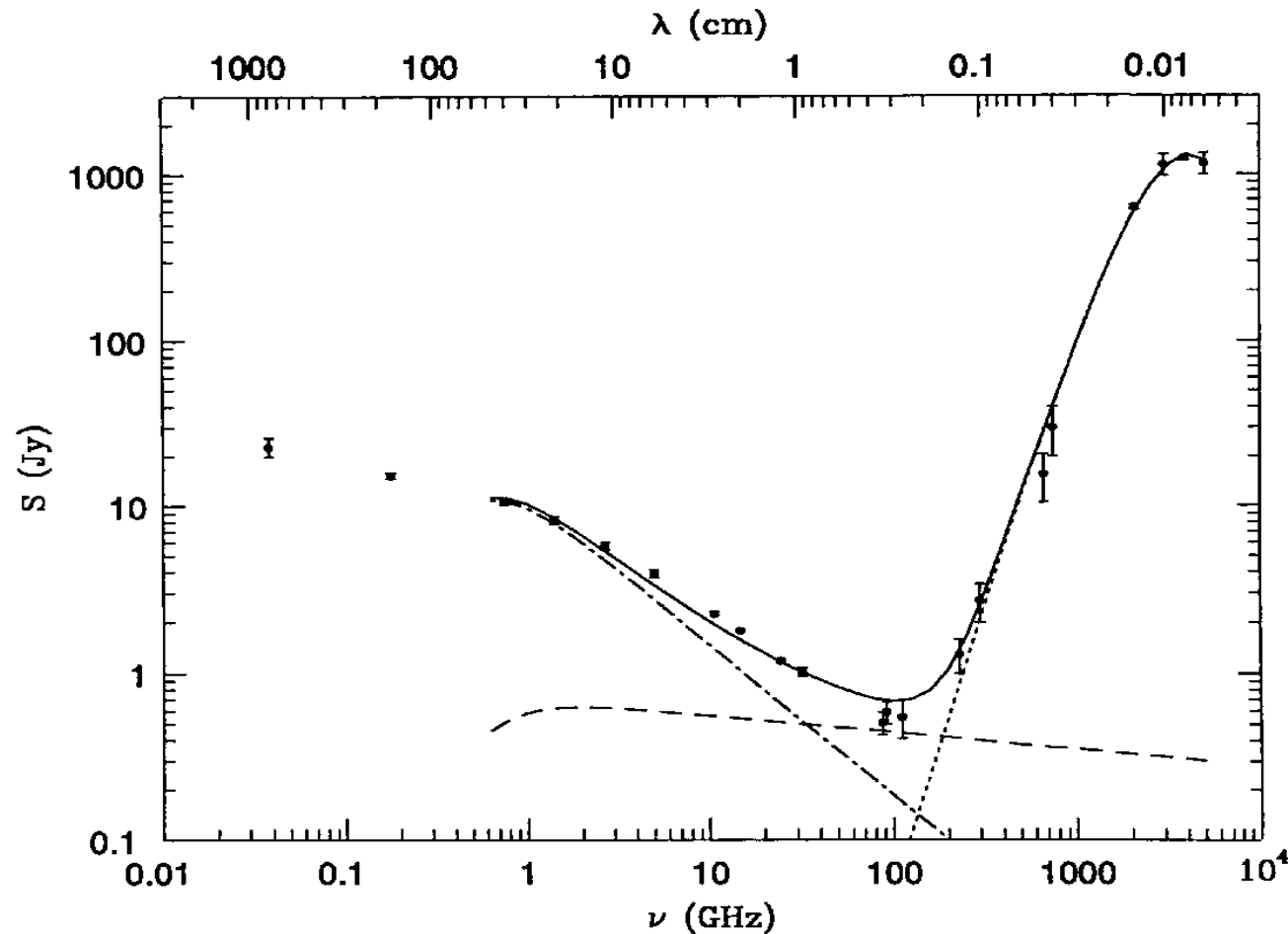
- Larmor's formula indicates that accelerating a charged particle produces electromagnetic radiation.
- In astrophysical situations the strongest accelerations of charged particles are produced by electromagnetic forces.
- Acceleration by an electric field accounts for free-free radiation.
- Acceleration by a magnetic field produces magnetobremsstrahlung, the German word for "magnetic braking radiation."
- Light charged particles (electrons and positrons if any are present) are more easily accelerated than the more massive protons and heavier ions, so electrons (and possibly positrons) produce virtually all of the radiation observed.
- The character of this radiation depends on the speed of the electrons, and these somewhat different types of radiation are given specific names.



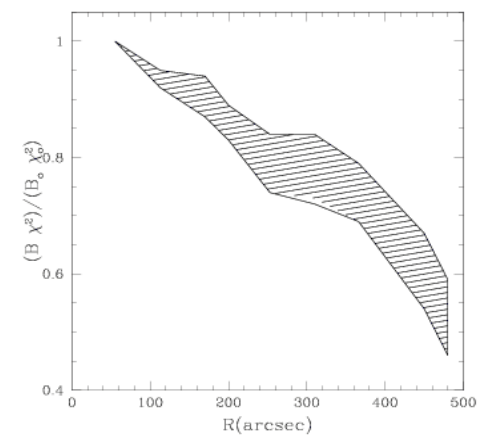
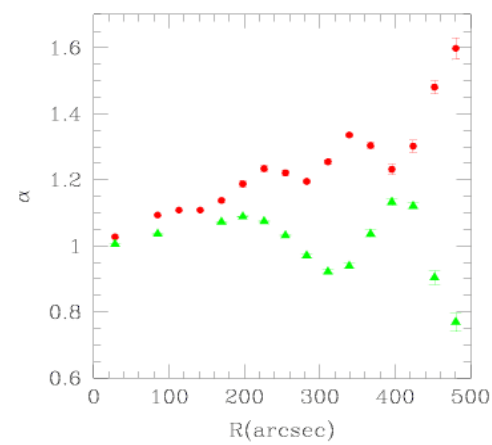
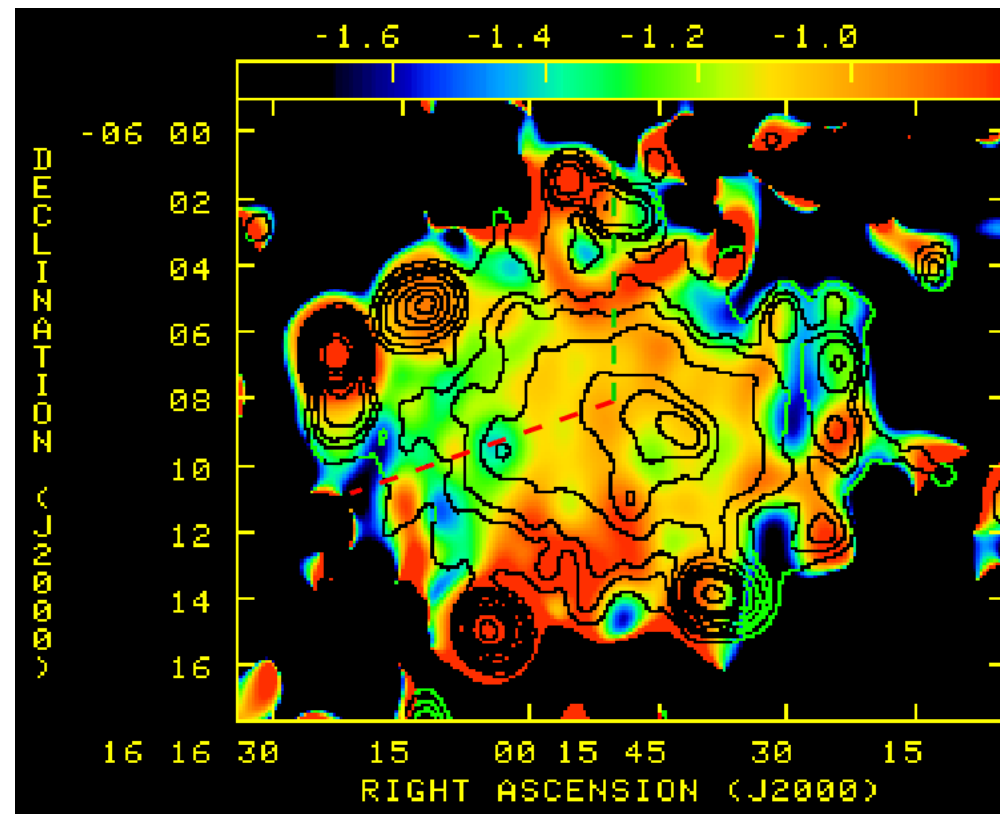
- Gyro radiation is produced by electrons whose velocities are much smaller than the speed of light: $v \ll c$.
- Mildly relativistic electrons (kinetic energies comparable with rest mass $\times c^2$) emit cyclotron radiation, and ultrarelativistic electrons (kinetic energies \gg rest mass $\times c^2$) produce synchrotron radiation.
- Synchrotron radiation accounts for most of the radio emission from active galactic nuclei (AGNs) in galaxies and quasars.
- It also dominates the low-frequency (30 GHz) emission from normal star-forming galaxies like our own.

Some measured parameters

- Flux density $S_\nu \propto \nu^{-\alpha}$
- S_ν - Flux density at frequency ν
 - 1 Jansky = $1 \text{ Jy} = 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}$
- α - spectral index
 - $\alpha = \ln(S_l/S_h) / \ln(\nu_h/\nu_l)$



- The radio and far-infrared spectrum of the nearby starburst galaxy M82. The contribution of free-free emission is indicated by the nearly horizontal dashed line. Synchrotron radiation and thermal dust emission dominate at low and high frequencies, respectively. Free-free absorption from HII regions distributed throughout the galaxy absorbs some of the synchrotron radiation and flattens the overall spectrum at the lowest frequencies.



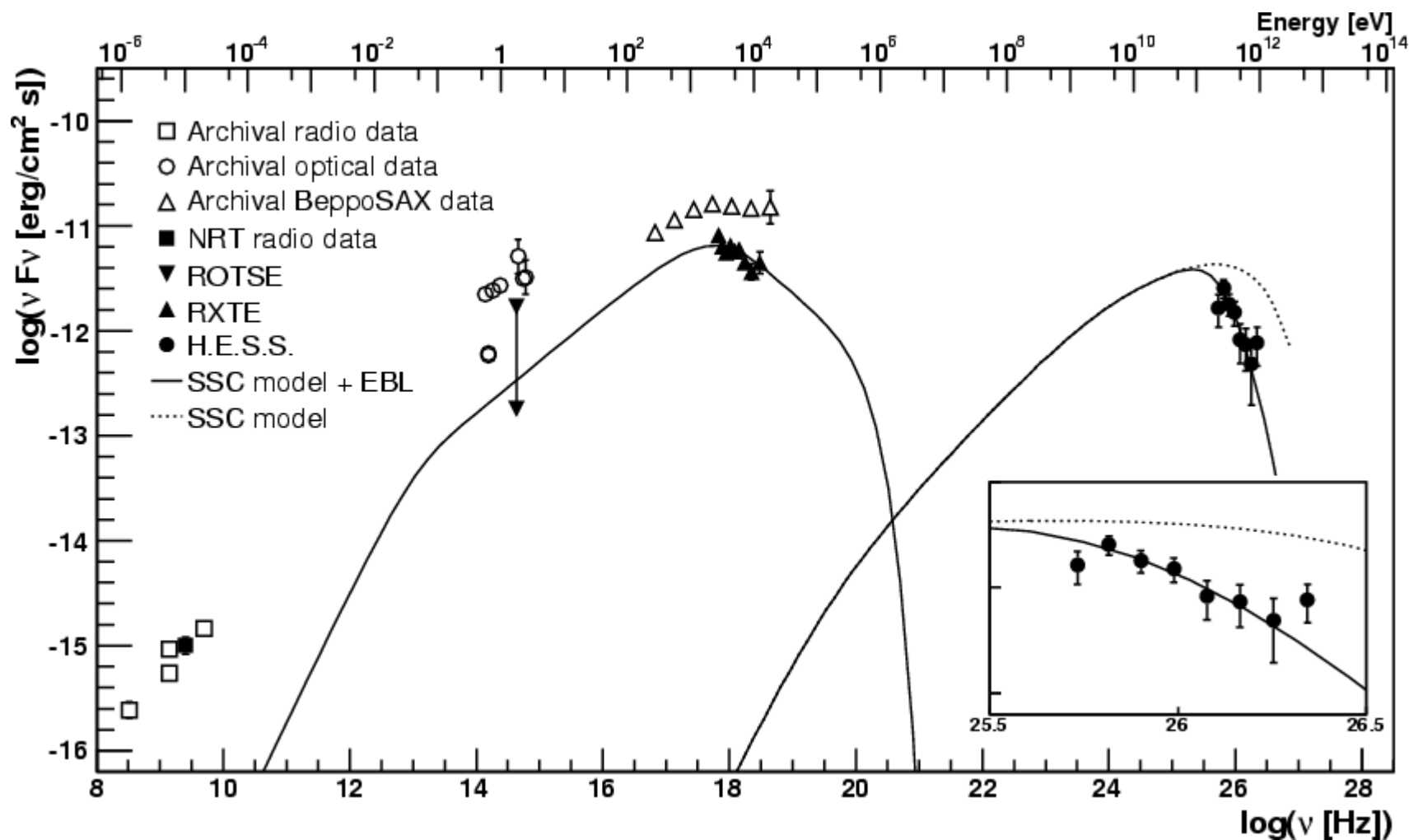
- Observational science
- The information is carried by photons (**of all wavelengths !**)
- The Laboratory is the **Universe**
- Experiments in the **Lab-Universe** were made, so far, with **telescopes**

What do we study ?

Waveband	Wavelength /Energy	Temperature	What can be studied
Gamma rays	100keV-100MeV	$>10^8\text{K}$	accretion disks, gamma-ray bursts
X-rays	$<1\text{-}100\text{keV}$	$10^6\text{-}10^8\text{K}$	Hot gas in clusters of galaxies, stellar coronae, accretion disks,
Ultra-violet	900-3000Å	$10^4\text{-}10^6\text{K}$	Hot stars, white dwarfs, instellar gas
Optical	3000-10,000Å	$10^3\text{-}10^4\text{K}$	Sun-like stars.
Infra-red	1-100 micron	$10\text{-}10^3\text{K}$	Dust, planets, brown dwarfs
Microwave	1cm	$<10\text{K}$	Background radiation of the Universe (remnant of Big Bang)
Radio	$>1\text{m}$	$<10\text{K}$	Radiation from electrons moving in a magnetic field: pulsars

- Rather annoyingly, astronomers use a variety of wavelength scales depending on the waveband involved
 - Radio astronomers use m and cm
 - Infra-red astronomers use microns
 - Optical and UV astronomers use Angstroms or nanometers
 - X-ray and gamma ray observers switch to an energy scale, i.e. in electron-Volts

SED of BL Lac object H 2356-309, located at a redshift of $z = 0.165$



- Astronomers used to think of themselves as either 'optical', 'radio', 'IR' or 'X-ray'
- But modern astrophysics requires studying an object across the whole EM spectrum
- Different physical processes can be studied at different wavelengths
- X-ray, gamma ray and radio astronomers need to identify their sources with optical counterparts

Technological revolution

- Radio & Space (**multi λ**) astronomy
- Digital imaging
- Large telescopes
- Fast computing
- World Wide Web
- Large digital Archives on-line

Data Mining

- Mining Large Data Sets as a discovery tool:
 - Exploit the multi-wavelength domain with statistical significance: base our knowledge on **billions** of objects instead than few **hundreths**
 - Explore the time-domain: discover transient phenomena like **Supernovae, Near Earth Objects, Gamma Ray Bursts**
 - Discover unkown, unexpected phenomena: **dark matter** and **dark energy** (*quintessence*) signatures ?

- On-line digital Archives do exist
- Friendly web interfaces for browsing and retrieving data do exist
- Analysis tools and affordable workstations do exist
- What do we need more than that ?
 - The Virtual Observatory (VO) is a concept under development for a system to allow transparent distributed data access across the world, allowing astronomers to discover, access, analyze, and combine astronomical data from huge heterogeneous data collections in a user-friendly manner.

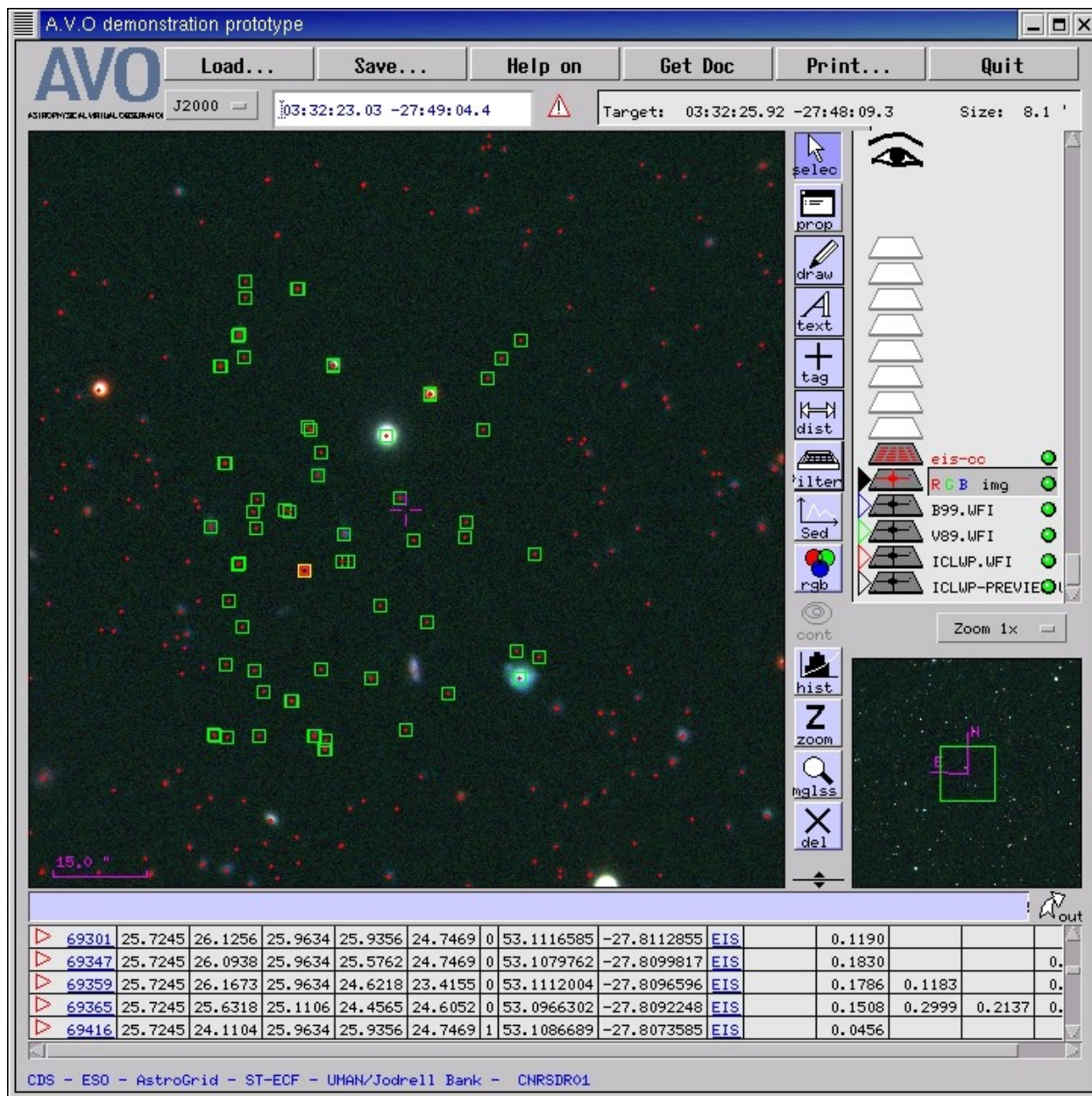


- Calibration, data quality and data description are highly non-uniform across Archives
- Merging multi-archive data is possible, but it is still a manual, tedious affair
- New instruments and surveys generate huge quantity of pixels (to be processed and analyzed...)
- Algorithms and analysis tools that can operate on distributed large data sets do not exist yet



SkyView

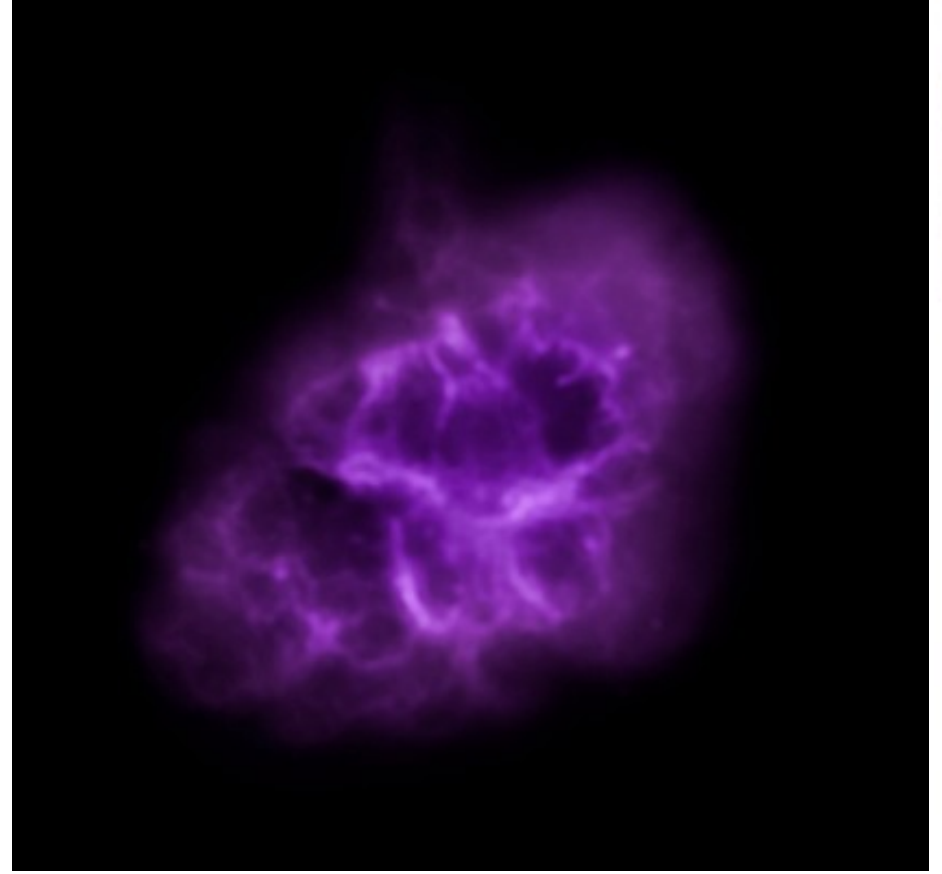
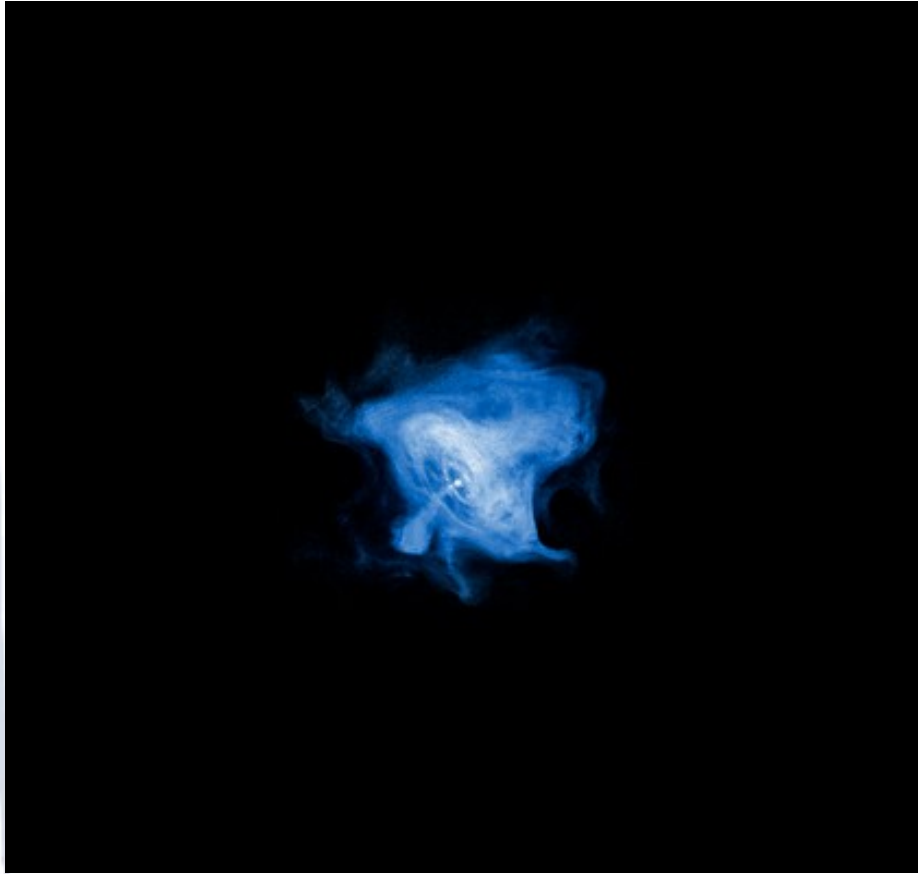
The Internet's Virtual Telescope



Crab Nebula

- The remnants of a star that exploded and that appeared in Earth's sky almost a thousand years ago.
- About 6,000 light years from Earth.
- By combining X-ray data from Chandra with optical data from Hubble and infrared data from Spitzer.

X-ray and IR

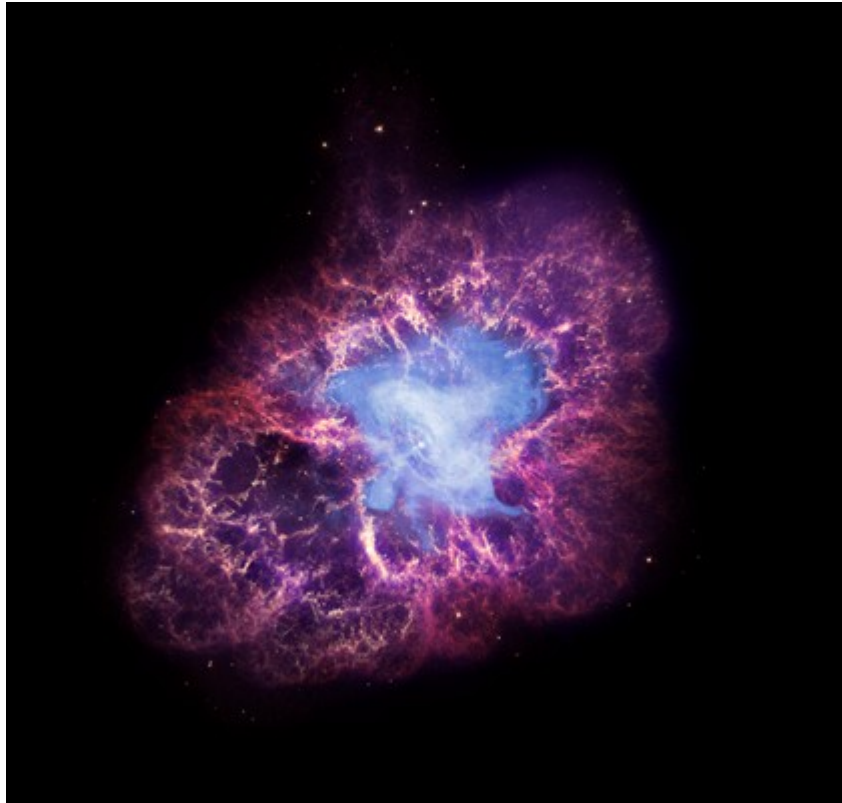


Optical



Composite image:

Blue represents the X-ray observations, red and yellow represent the optical, and purple represents the infrared.



Credit: X-ray: NASA/CXC/SAO/F.Seward; Optical: NASA/ESA/ASU/J.Hester & A.Loll; Infrared: NASA/JPL-Caltech/Univ. Minn./R.Gehrz

Galaxy clusters



Galaxy clusters

- Galaxy clusters are the largest gravitationally bound system in the Universe, composing of ~ 30 to 1000's of galaxies, diffuse, hot gas, and dark matter
- Most galaxies exist in groups/clusters
- Clusters are in super clusters
- Clusters and superclusters of galaxies have been studied extensively both for
 - their intrinsic properties and
 - to investigate the dark matter in the universe, the baryon content of the universe, large-scale structure, evolution, and cosmology.

X-ray view

- X-ray studies of groups of galaxies provides information about the environment and the process occurring therein.
- For instance, the presence of diffuse X-ray emission in a group would indicate the group is likely to be gravitationally bound whereas temperature, luminosity and surface brightness profile provide information concerning the depth of the potential well and the distribution of mass in the system.



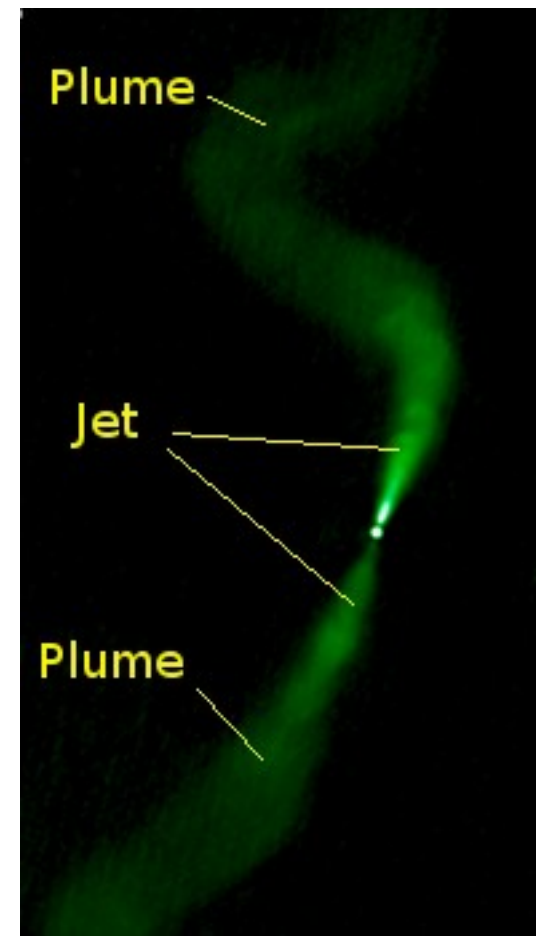
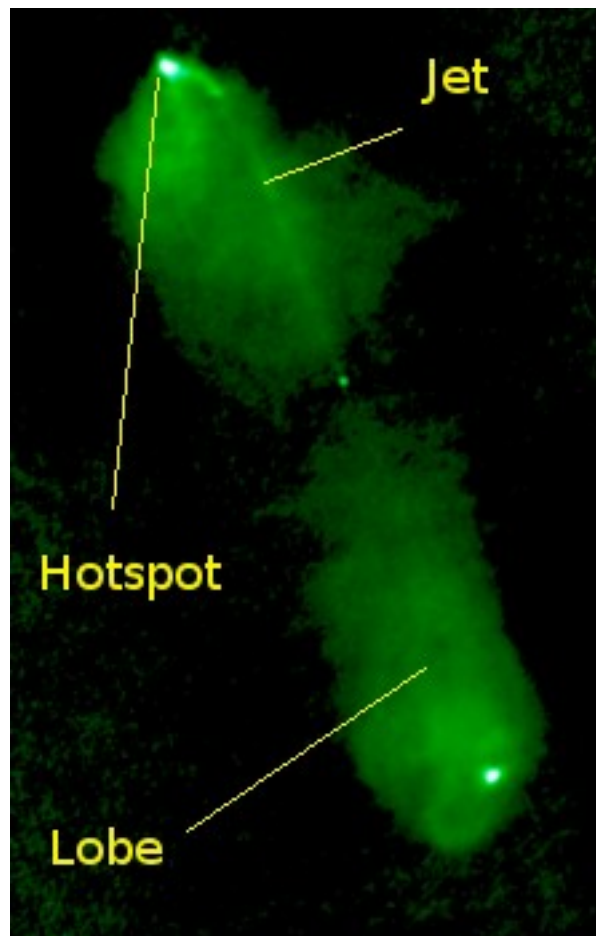
Optical view

- Typical Properties of Clusters and Groups
- Distribution of Clusters with Richness and Distance
- Number Density of Clusters
- Fraction of Galaxies in Clusters
- Galaxy Overdensity in Rich Clusters
- Density Profile
- Central Density and Core Size
- Galactic Content in Rich Clusters
- Velocity Dispersion

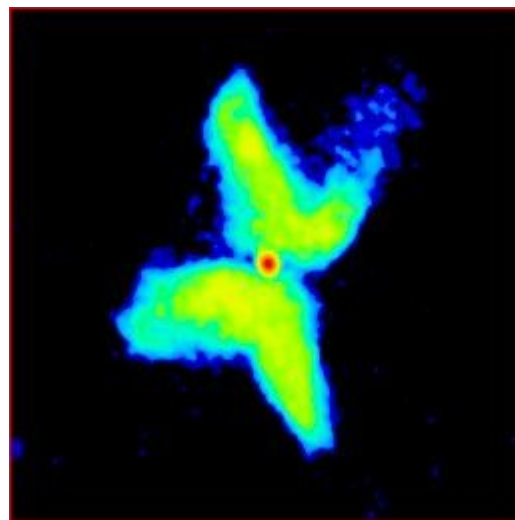
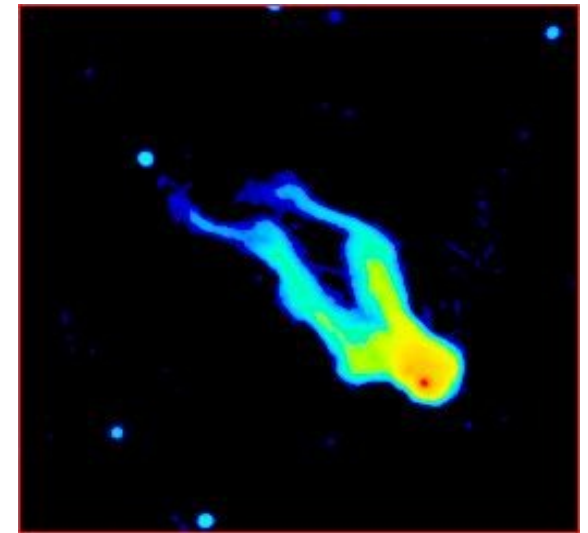
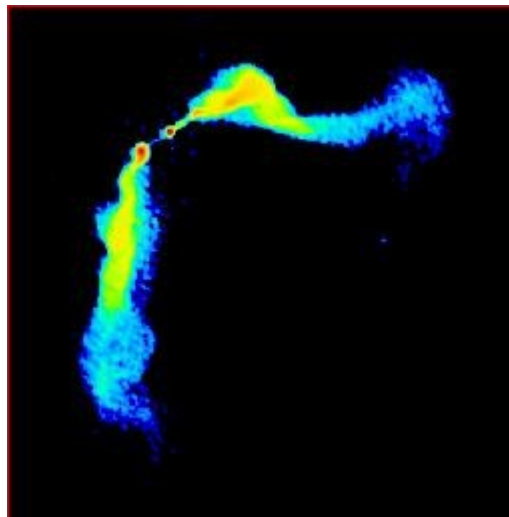
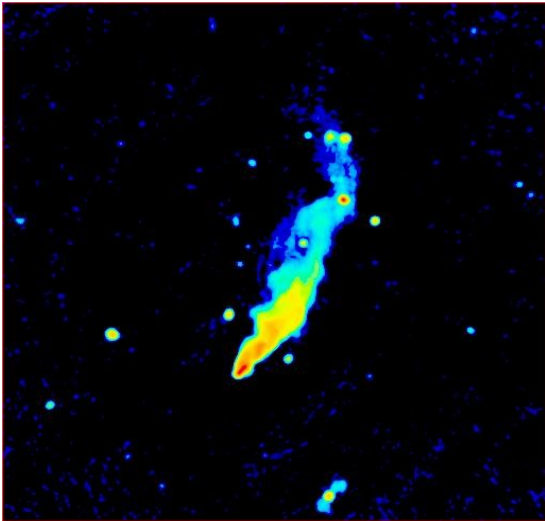
Radio galaxies

- Active galaxy: emit more luminously than normal galaxy
- They are powered by a central engine : Active Galactic Nucleus (AGN)
- Radio galaxies and radio-loud quasars show (hereafter all called radio galaxies)
 - twin jets of radio-emitting plasma
 - High radio luminosity 10^{38} W [10MHz 100 GHz]
 - The radio emission is synchrotron radiation: plasma containing relativistic electrons and magnetic field.
- Two type of radio galaxies : Low power (FRI) and high power(FRII)

FRI and FR II class



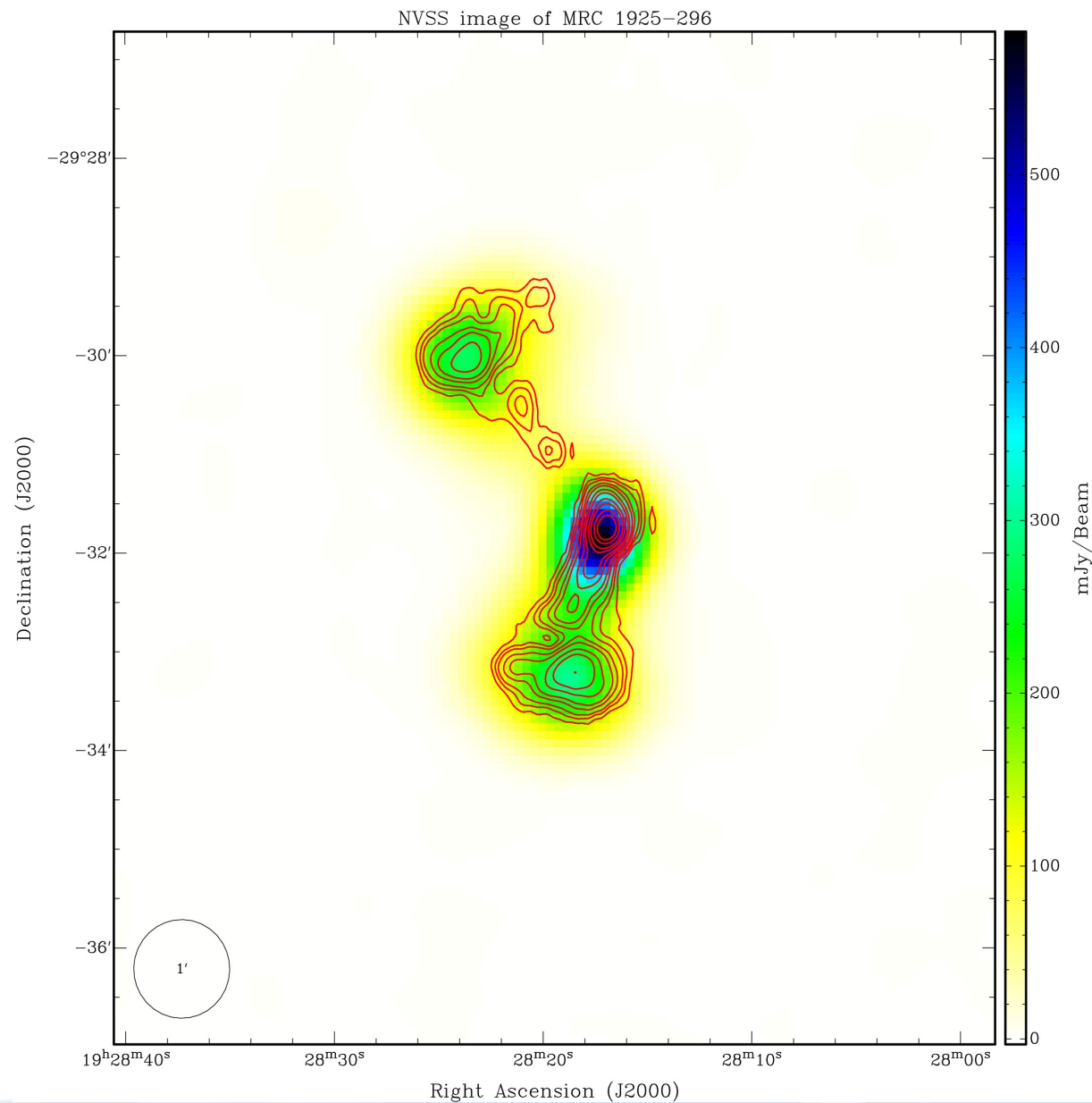
Morphology of radio galaxies



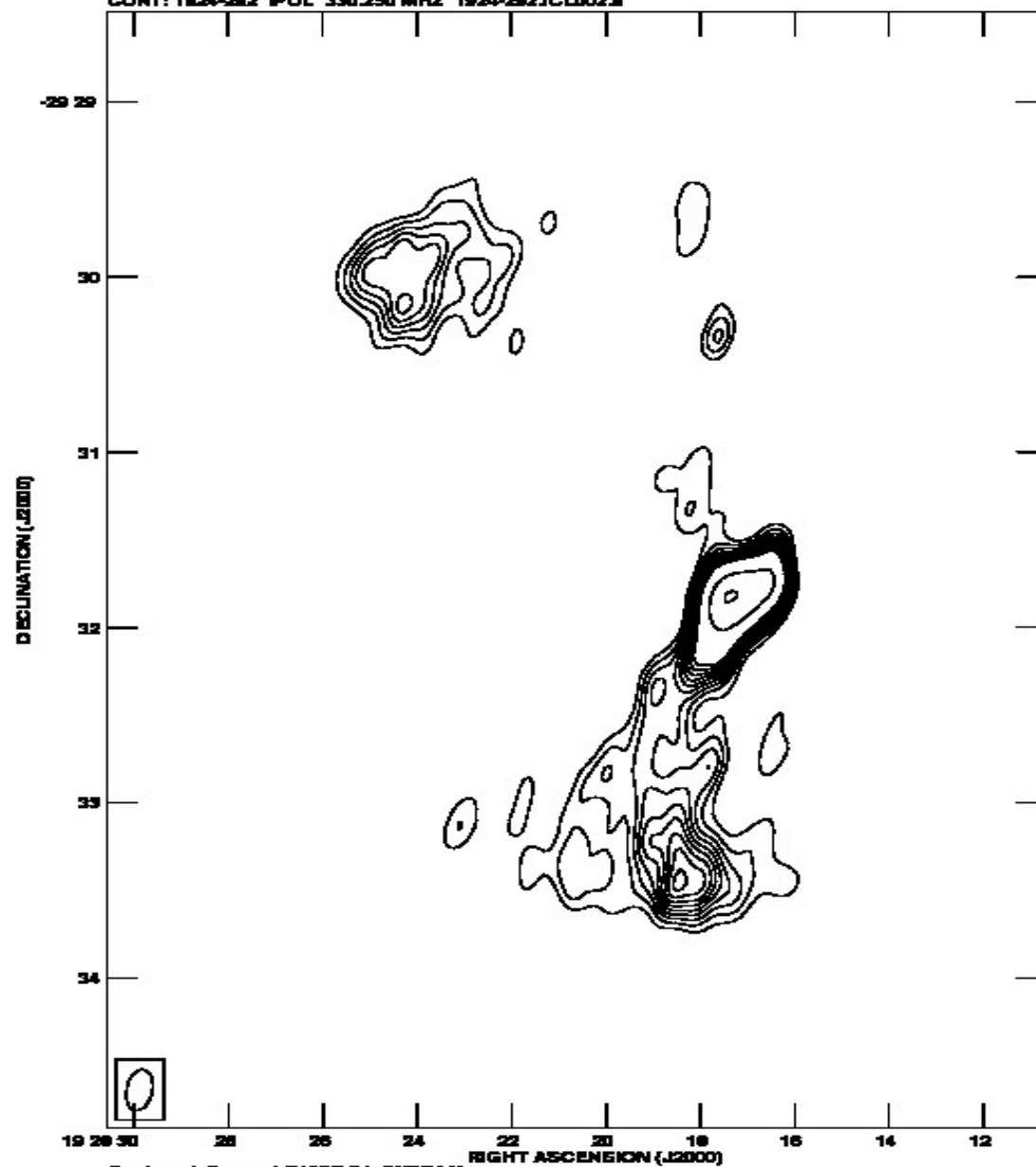
MRC B1925-296

- Detected from a survey of 120 sources in radio
- Check
 - other radio archive
 - Optical – redshift very important
 - Other wavelengths data
- Check for similar work
- Work on your own data and come up with novel methods or try to consolidate what others have seen

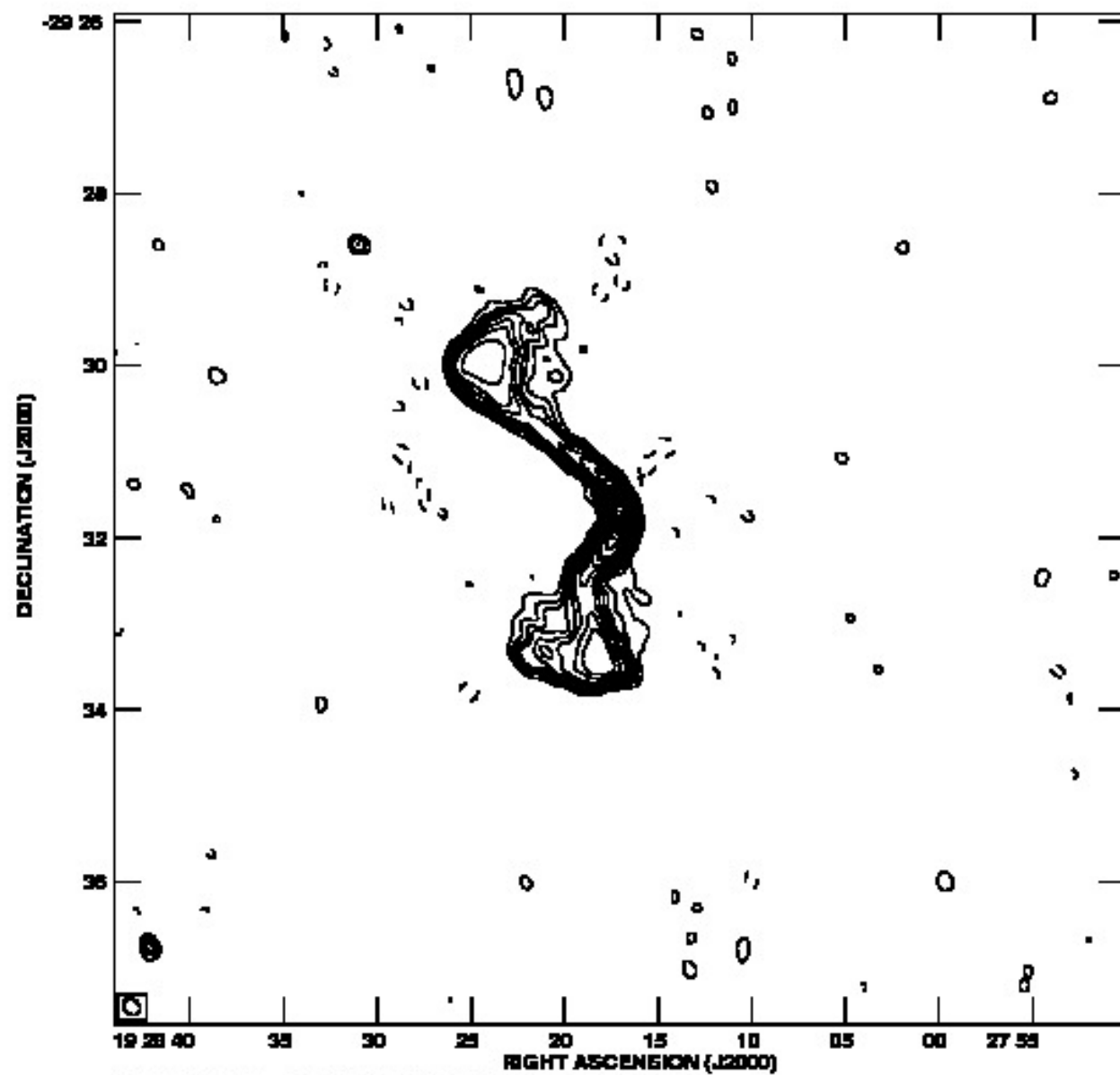
What do we have ?



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CONT: 1924-2912 POL 330.250 MHz 1924-2912.JCL002.B

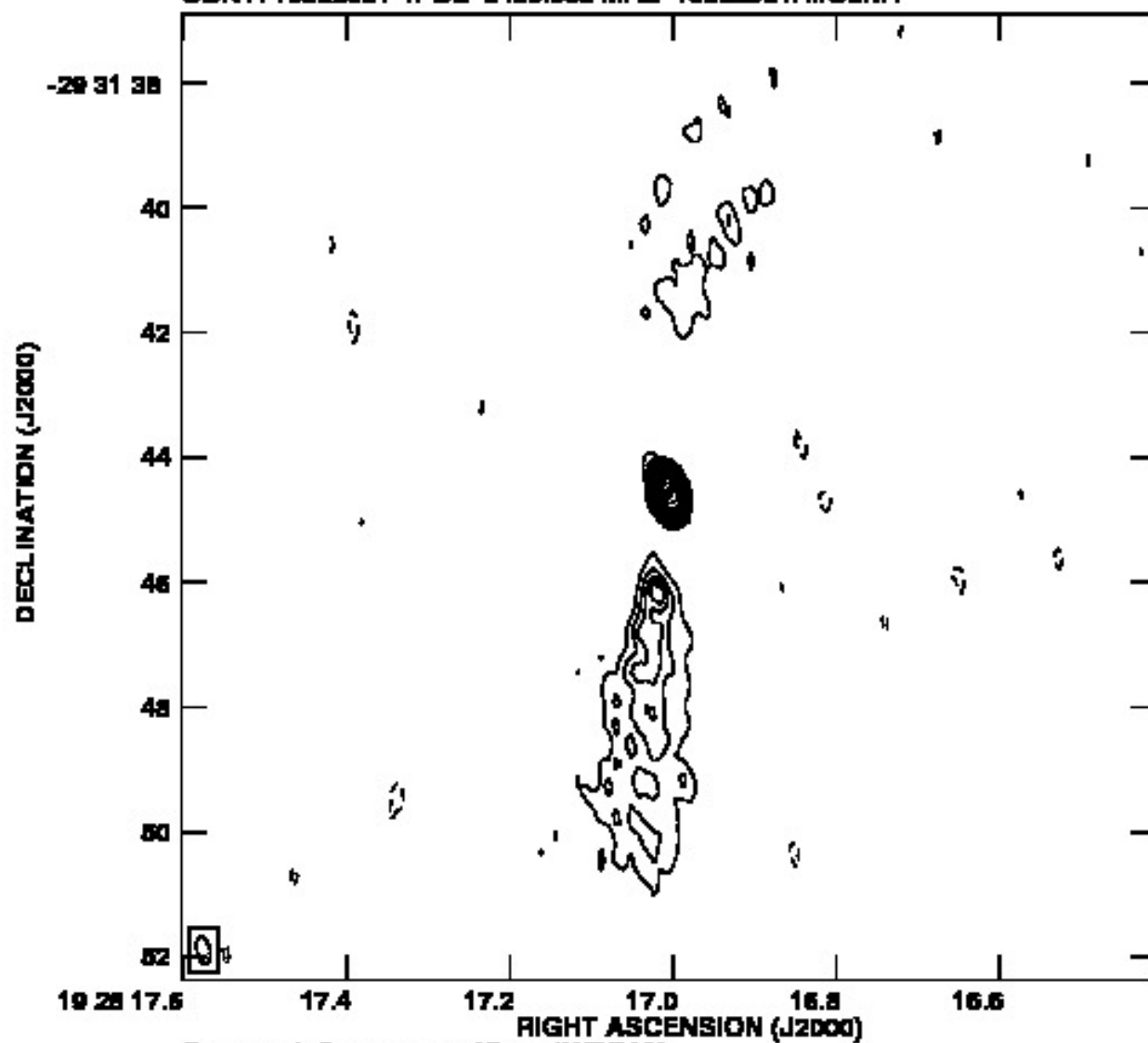


Cont peak flux = 1.7405E-01 JY/BEAM
Lvl = 1.1375E-02 * (1, 1.500, 2, 2.500, 3, 3.500,
4, 4.500, 5, 10, 15)

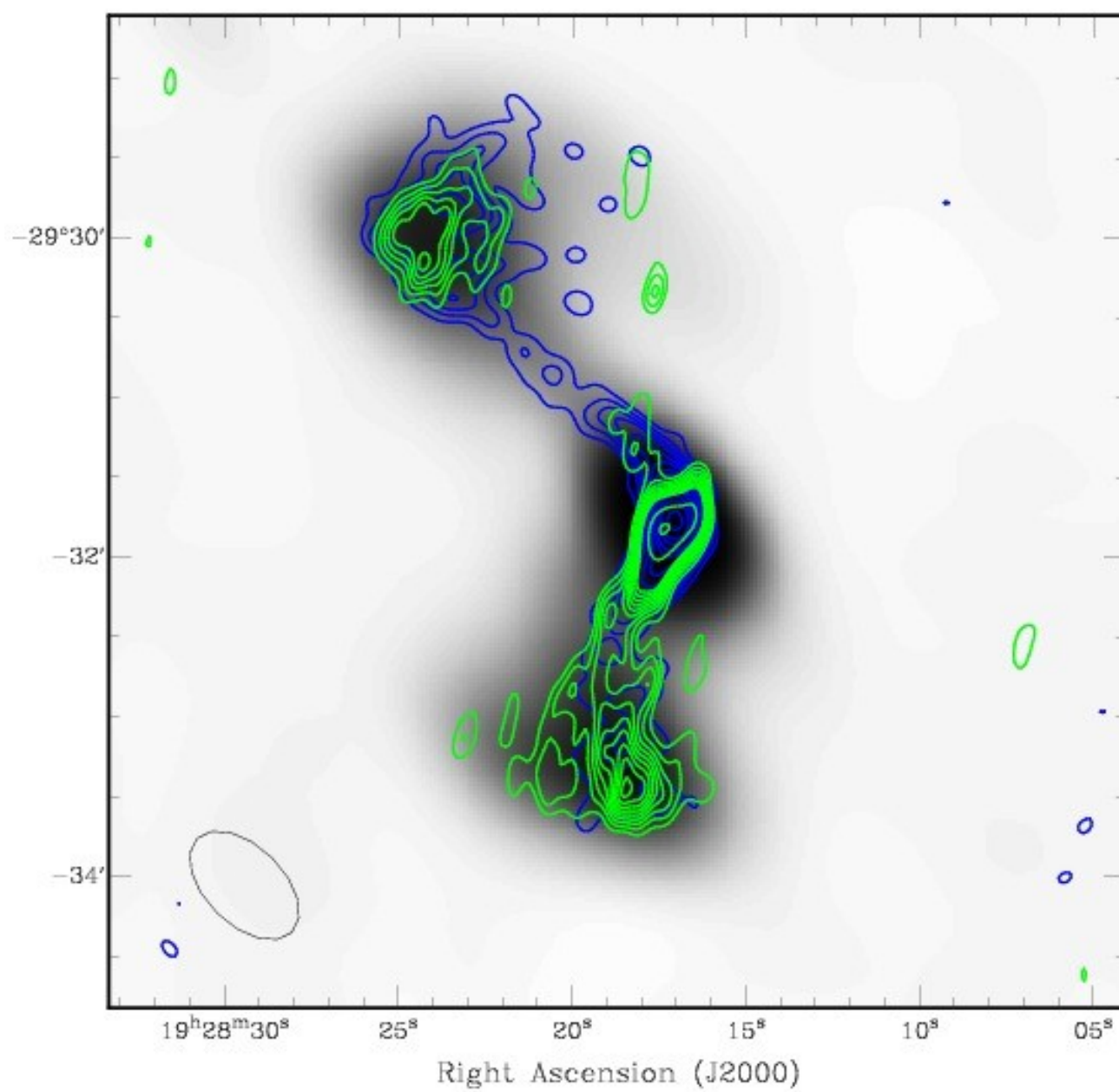


Cont peak flux = $1.7231\text{E-02 JY/BEAM}$
 Levels = 8.2845E-03 (-1, 1, 2, 3, 4, 8, 8, 12, 18,
 24, 32, 48, 64, 86, 128, 182, 256)

Plot file version 1 created 13-SEP-2008 23:14:40
CONT: 19282931 IPOL B439.900 MHZ 19282931H.ICLN.1



Cont peak flux = 3.7954E-02 JY/BEAM
Levs = 5.023E-04 * (-1, 1, 2, 3, 4, 5, 8, 12, 16,
24, 32, 48, 64)



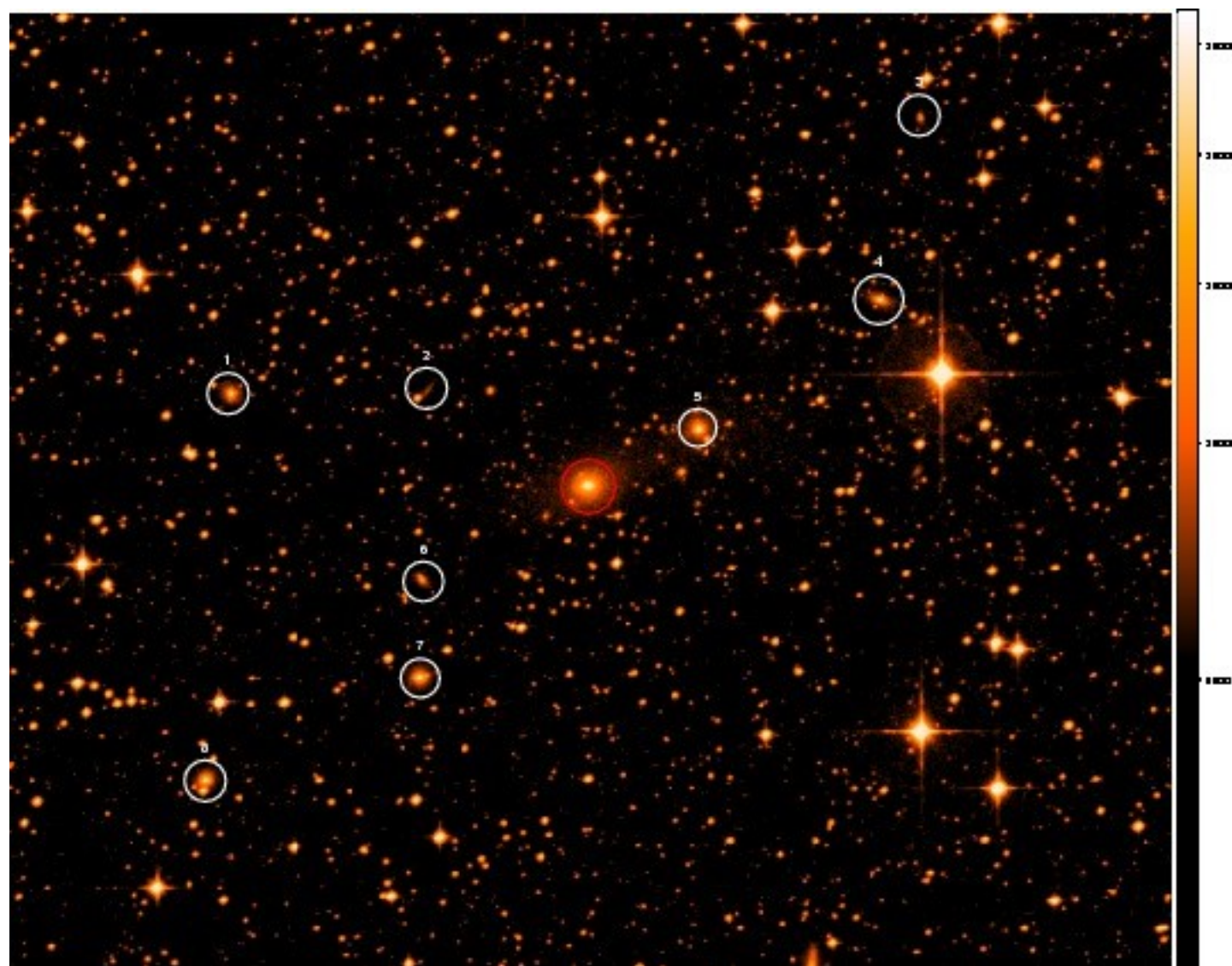


	S_{618} [Jy]	$S_{1.4}$ [Jy]	α_{618}^{1400}	Vol [cm ³]	$L_{1.4}$ [WHz ⁻¹]	S_{bol} [Wm ⁻²]	L_{bol} [ergs ⁻¹]
N1	1.719	0.520	1.46	1.58×10^{72}	6.3×10^{23}	6.5×10^{-15}	7.6×10^{42}
S1	0.972	0.511	0.78	1.29×10^{72}	6.2×10^{23}	3.7×10^{-15}	4.2×10^{42}
Core	1.067	0.808	0.34	4.39×10^{70}	9.8×10^{23}	4.1×10^{-15}	4.6×10^{42}
Total	3.999	1.838	1.00	2.92×10^{72}	2.2×10^{24}	1.4×10^{-14}	1.6×10^{43}

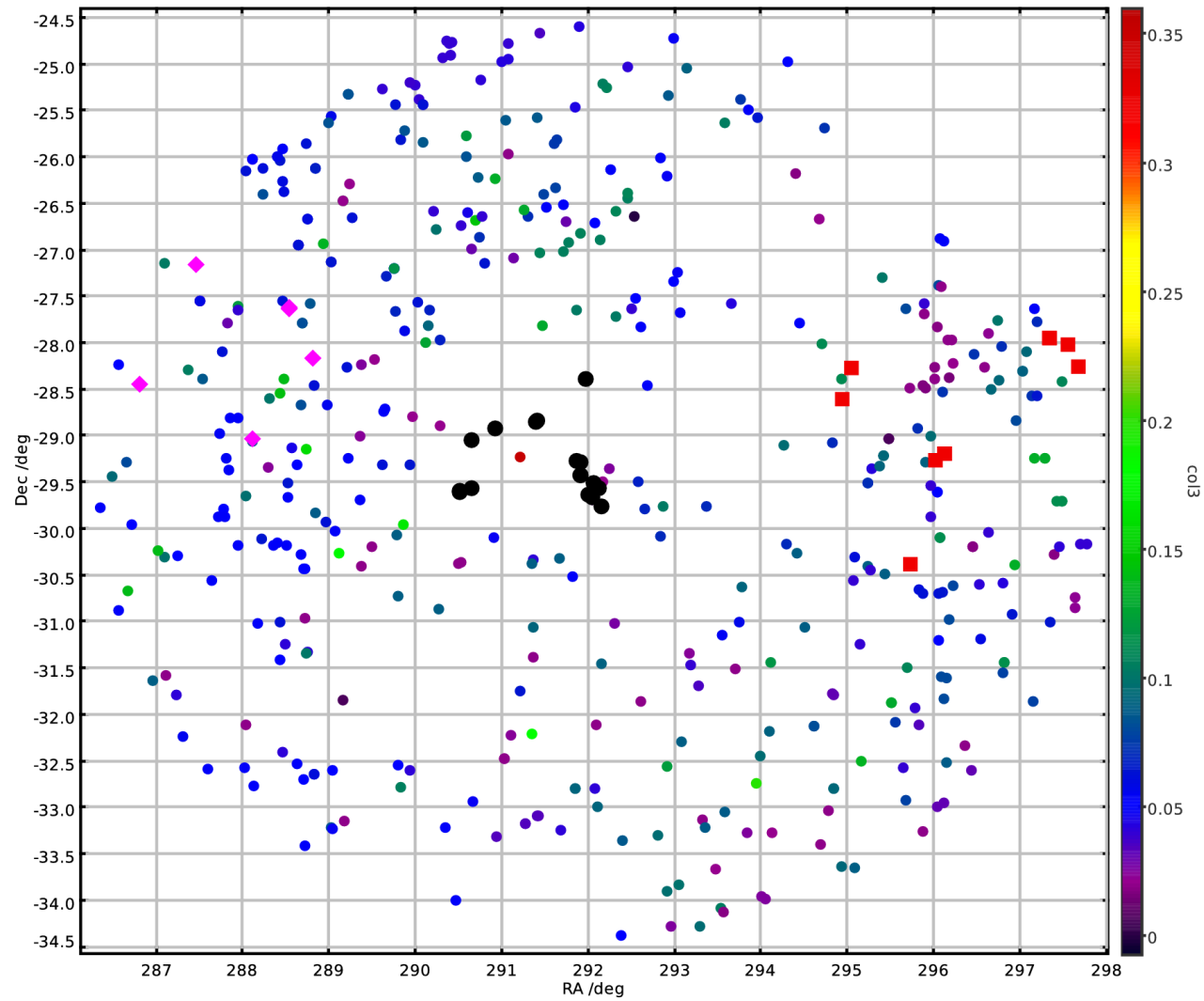
Table: Physical parameters for MRC 1925-296.

Components	U_{min} [erg]	E [Jm ⁻³]	P [Pa]	B(U_{min}) [nT]
N1	7.57×10^{60}	4.79×10^{-11}	1.60×10^{-11}	0.71
S1	4.97×10^{60}	3.84×10^{-11}	1.28×10^{-11}	0.64
Core	1.22×10^{60}	2.78×10^{-10}	9.27×10^{-11}	1.72
Total	1.38×10^{61}	4.71×10^{-11}	1.57×10^{-11}	0.74

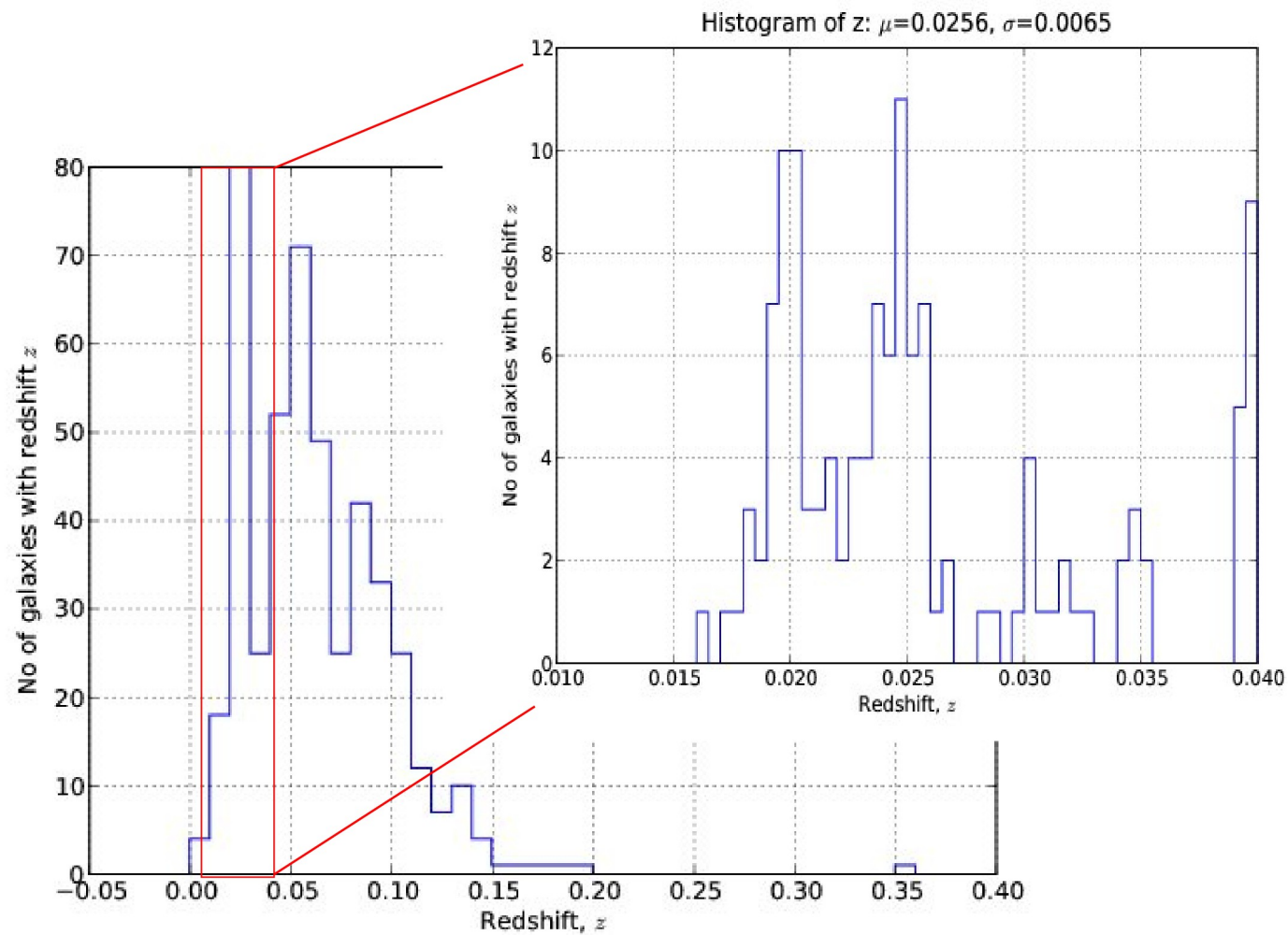
Table: Energy density and pressure for the 3 different components.



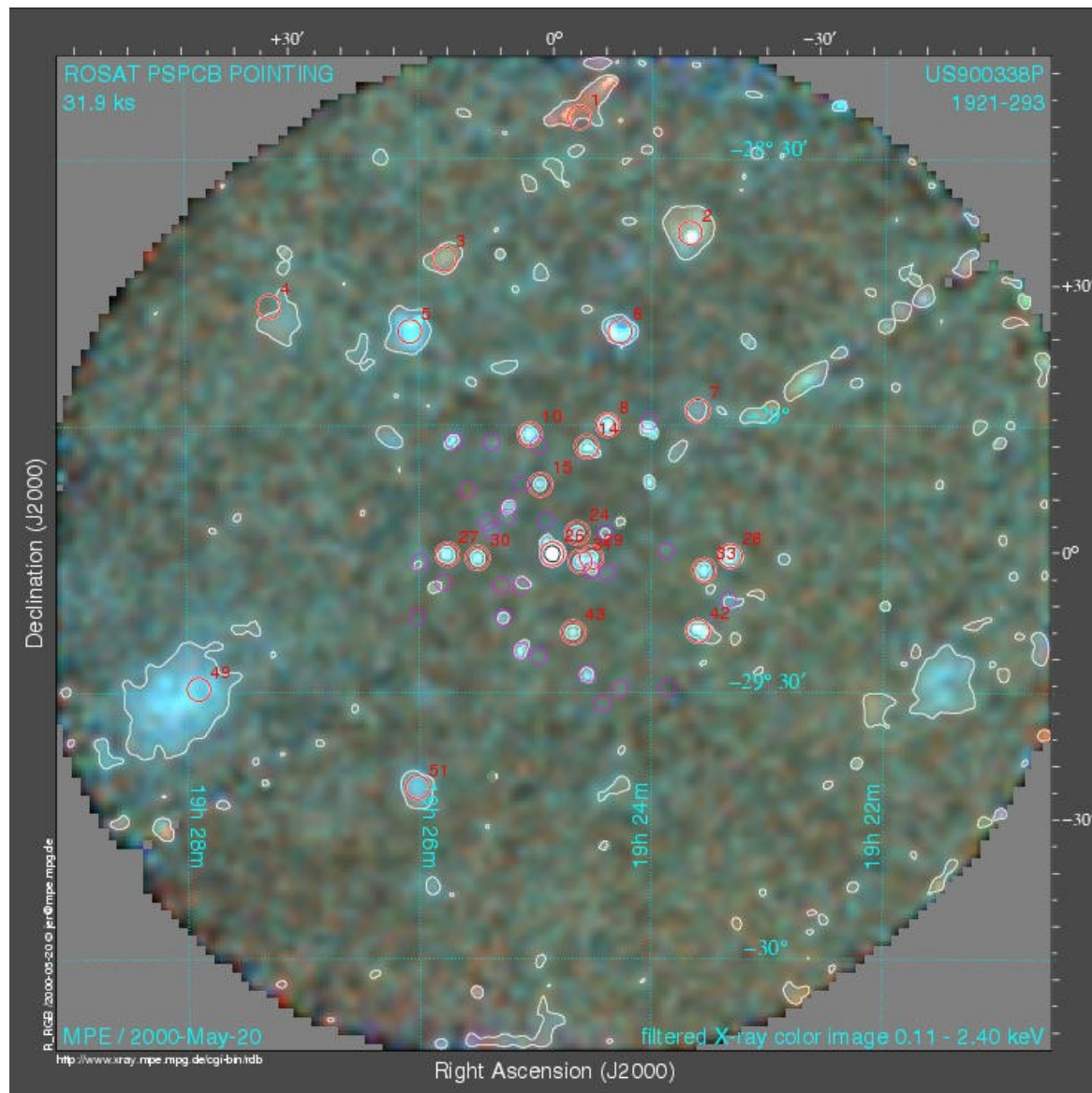
Scatter plot of galaxies 5deg Field



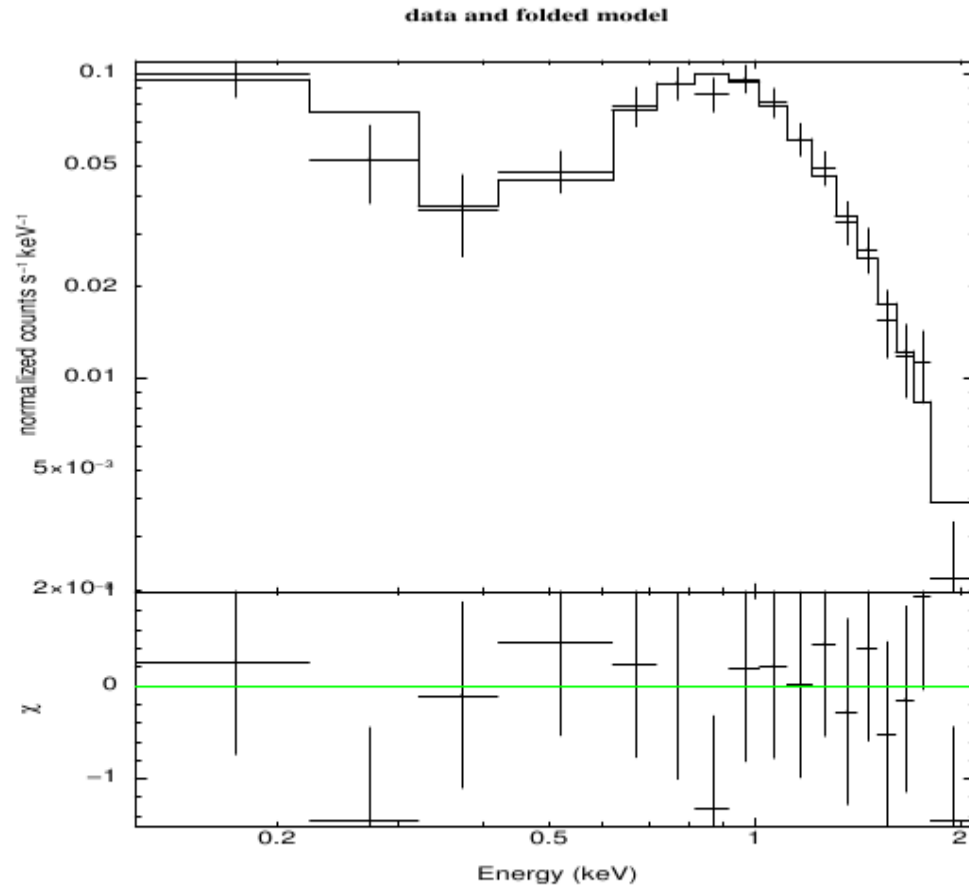
Statistical analysis



ROSAT perspective



X-ray analysis



Parameter		Value
nH	cm ⁻²	$6.6 \pm 3.6 \times 10^{-20}$
kT	keV	$89.3 \pm 9.3 \times 10^{-2}$
Abundance		2.8×10^{-2} (fixed)
norm		$51.1 \pm 9.4 \times 10^{-4}$

Table: Model used

(zphabs*raymond + raymond)

Chi-Squared = 9.2 using 20 PHA bins.

Reduced $\chi^2 = 0.57$ for 16 dof.

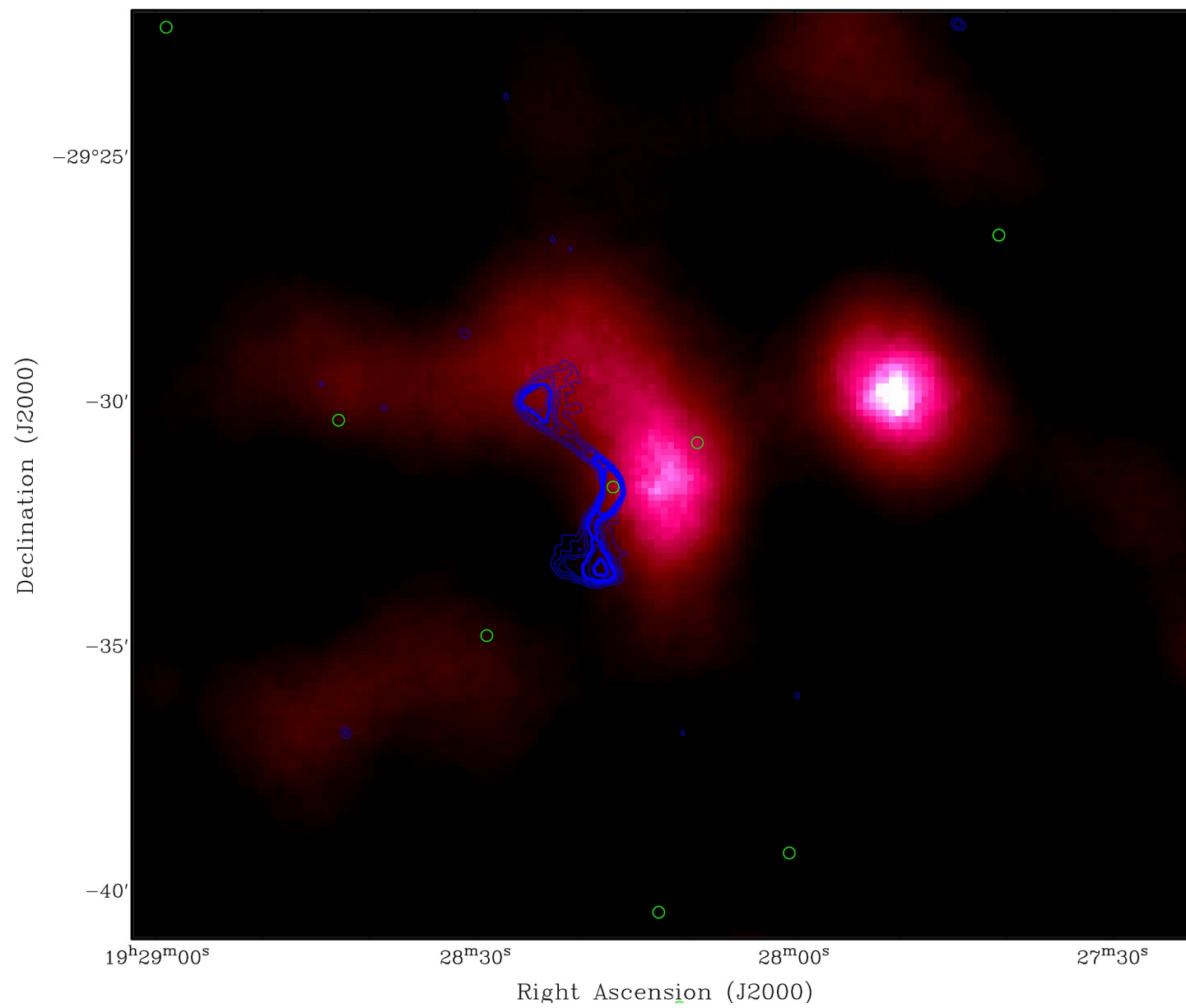
Null hypothesis probability = 9.05×10^{-1}

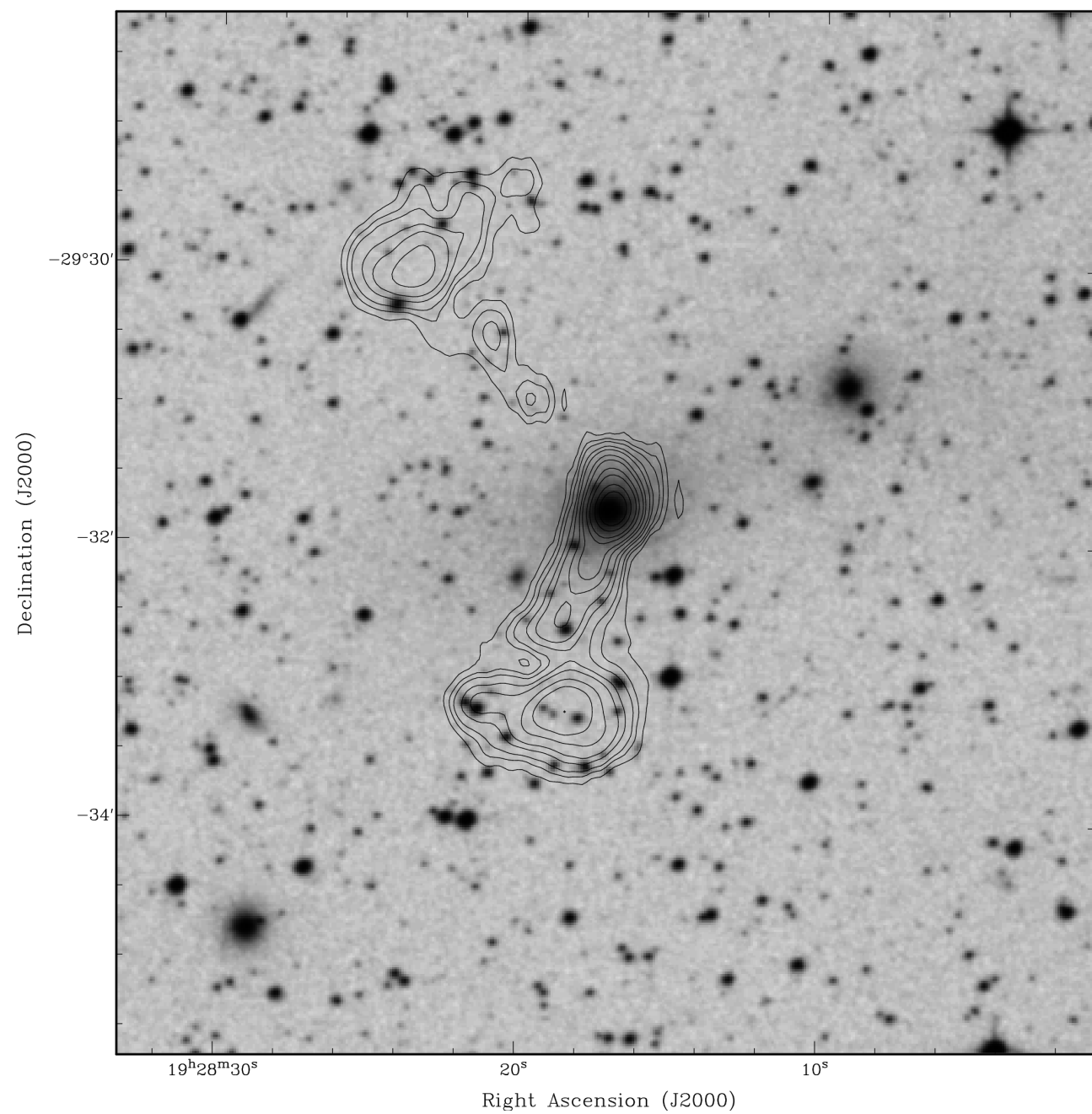
$L_* = 2.2 \times 10^{42} \text{ ergs}^{-1}$.

Linear size = 390 kpc.

The value of the hydrogen column density is similar to that calculated by Dickey et al (1990) ($N_H = 8.29 \times 10^{20} \text{ cm}^{-2}$) in galactic absorption at the source position.

Fig: Spectrum around X-ray peak in cluster up to a radius of $9''$.





Try to Understand system

- Possible cause of the bending
 - Merger
 - Cool clump
 - Gravitational interaction

Ingredients for Bent radio sources



Hands on session

- Ds9
- Karma
- aips